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ANCHORAGE

LIMNOLOGY OF WALKER LAKE AND COMPARISONS WITH OTHER LAKES IN THE BROOKS RANGE, ALASKA USA

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July 27, 1989

Judy Alderson
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Fairbanks, AK 99707-4680

Dear Judy:

Thanks a lot for making the study of Itkillik Lake possible. Jackie and I appreciate all your time, help and interest in the project. We recognize that organizing a project like ours takes a great deal of extra commitment on your part.

Both Jackie and I enjoyed our stay at the lake and are excited by the data set. Only a few numbers have come out of the laboratory but it seems that nitrogen was more important than phosphorus in regulating algal biomass in Itkillik Lake. This result is opposite of our findings in Walker Lake. Based on a few measurements, it looks as if algal biomass in Itkillik was low but about double the value found in Walker Lake. Like Walker, algal biomass was much higher in the deeper waters of Itkillik Lake than at the surface.

Enclosed is our final report on Walker Lake. Our findings will be presented at an International Limnology meeting in August 1989 and the paper will be published in the proceedings. This meeting and subsequent publication is a good outlet for this work because it is considered a "source" for information on high latitude lakes.

Walker Lake is an interesting waterbody and it deserves a detailed study. Our evaluation scratches the surface about the characteristics of this lake and raises more questions than it answers. What we did find is that Walker Lake is an unproductive lake with low algal biomass. It, however, has a surprisingly high nitrogen content. We have made some guesses at why nitrogen occurs in such a high amount in this remote lake and the soil scientists seem to agree with our speculation. Because nitrogen levels are so high, phosphorus is the element regulating algal biomass in Walker Lake. Our Nutrient Enrichment Experiments showed that the plankton responded to additions of phosphorus and nitrogen is in sufficient supply to grow algae. The reason that Walker Lake is so unproductive is that phosphorus levels in the lake are extremely low.

From a management perspective, the key to protecting water quality in Walker Lake is regulating the amount of phosphorus entering the lake. My background as a limnologist and our data set from Walker Lake cause me to make that statement. Logic and reason, however, lead me to believe that Walker Lake is not currently experiencing enrichment problems. The present use of the lake by campers is probably having a minor effect on the fertility of this large lake. And, if for some reason the present use of Walker Lake increased by several fold the impact on the lake would probably be minor.

Additional phosphorus from a significant source such as development within the watershed, however, will definitely increase the amount of suspended algae in the water column of Walker Lake. The result will be that the lake will become less transparent. An example is provided within the present data set. The north basin of Walker Lake is somewhat more fertile than the south basin (likely because the major streams enter at the north end). In the north basin algal biomass (as chlorophyll a) is about 0.4 ug/L and the Secchi disk transparency is about 14.5 meters. In the south basin chlorophyll averages about 0.2 ug/L and the Secchi transparency is nearly 17 meters. For the purposes of comparison, in Itkillik Lake algal chlorophyll was 0.9 ug/L and Secchi transparency was about 10 meters. With additional phosphorus inputs to Walker Lake algal biomass values will increase and the transparency will decrease to a point where they will be more like the values in Itkillik Lake. The potential benefits of enriching Walker Lake is that increased algal productivity will likely translate into increased fish harvest from the lake. This statement, however, is based on ecological theory and at the present time I can not describe the relation between algal biomass and fish harvest in arctic lakes.

Two aspects of limnology in Walker Lake have captured our interest. First, we would like to know more about the factors controlling the distribution of algal biomass with depth in this lake. The broad peak of algae located between 20 and 30 meters probably represents the region of greatest productivity within the water column. We would like to know how it is formed and how it changes over time. Second, there seems to be an abundant growth of algae on the bottom of Walker Lake. We think that growth may be important in the food web of that water body and wish we had been prepared in 1988 to make some measurements.

I think you can tell from the tone of this letter that Jackie and I are extremely interested in the lake within the Gates of the Arctic National Park. Based on the data from Walker and Itkillik lakes it seems that factors regulating algal biomass within these two lakes differ. In the future we would like to spend time on other waterbodies within the park to determine whether there is a pattern to this finding. Perhaps there is a east-west or north-south gradient to the relative role of phosphorus and nitrogen limitation of algal biomass within these lakes.

Jackie and I have talked at length about the lakes in Gates of the Arctic. If we were to design another small-scale study of lakes within the Park, we probably would study lakes Selby and Narvak. Our approach would be similar to the previous studies on Walker and Itkillik lakes. The major purpose would be to determine nutrients and algal levels, and assess whether phosphorus or nitrogen was most important in regulating algal biomass. Also, if it could be arranged, it would be worthwhile to spend one or two days sampling a variety of lakes within the park from the float plane. We could learn a great deal about these remote waterbodies by taking grab samples off the floats and making comparisons. These flights could be done using Bettles as a base of operation.

Again, thanks for your support. I look forward to our association.

Sincerely yours,

Jack

John R. Jones
Professor

Limnology of Walker Lake and comparisons with other lakes in the Brooks Range, Alaska (USA)

John R. Jones, Jacqueline D. LaPerriere and Bruce D. Perkins

With 4 figures and 2 tables in the text

Introduction

This paper summarizes limnological data collected from Walker Lake, a deep arctic lake within the Brooks Range, Alaska. Our purpose was to document conditions in this remote waterbody with particular emphasis on chemical content, distribution of algal biomass within the photic zone and nutrient limitation of the phytoplankton. Also, we present data from lakes located nearby and draw comparisons.

Site Description

Walker Lake (67°08'N 154°21'W) is located on the south facing slope of the Brooks Range in the Gates of the Arctic National Park and Preserve. It is impounded by terminal moraines of the Itkillik II glaciation (Fernald 1964) at an altitude of 194 m in the headwaters of the Kobuk River (Figure 1, after Reanier 1986). It lies in a steep NW-SE directed valley and has two major basins, each 120 m deep, separated by a shallow sill. The northern basin is elongate and symmetrical; the southern basin is complex with several ridges and troughs (Reanier & Anderson, undated). The lake is 21 km long, with a surface area of 3751 ha, volume of 2.3 x 10^9 m^3, maximum depth of 122 m, mean

depth of 61.1 m, and shoreline length of 94 km (calculated from Reanier 1986). The Brooks Range in the vicinity of Walker Lake is formed of sedimentary rock of Paleozoic age and includes limestone, shale, chert conglomerate, and sandstone (Nelson & Grybeck 1980). Walker lake lies near the transition of the boreal forest and alpine tundra.

Methods

Samples collected from Walker Lake during 6 to 11 July 1988 at five sites and all inflowing streams (Figure 1) were processed in a field camp by taking aliquots for chemical and chlorophyll measurements; most analyses were conducted in duplicate or triplicate at the University of Missouri (APHA 1985). Total nitrogen was measured on acid-preserved samples by persulfate digestion (D'Elia et al. 1977) followed by cadmium reduction. Total phosphorus was measured by persulfate digestion followed by the molybdosilicate method. Chlorophyll *a* (chl *a*) and phaeophytin were determined by fluorometry (Knowlton 1984) after extraction in hot ethanol (Sartory & Grobbelaar 1984). Cations were determined on acid-preserved samples by using a flame photometer or atomic absorption spectrophotometer.

We also collected samples from the surface of Lake Nutuvukti in July 1988. Personnel of the U. S. Fish and Wildlife Service collected samples from five lakes in the Brooks Range during summer 1987 (Table 1) and samples were analyzed at the University of Missouri.

Results

Salinity--Waters of Walker Lake (Table 1) were of the bicarbonate type, characterized by a predominance of Ca among the cations (80%) and HCO_3 among the anions (84%). On average, Mg comprised 16%, and the monovalent alkali metals constituted <4% of the cation equivalents. Among the anions, sulfate accounted for 15% and Cl made up <1%. Concentrations and ionic proportions of each major element in the lake water were similar to values in the discharge-weighted average of inflowing streams (Table 2).

Salinity in Walker Lake matched the world average for freshwaters (cation equivalents=1.42 meq/L, Wetzel 1983) but was some 2-7 times greater than the other lakes sampled in the Brooks Range (Table 1). Composition of cations in Walker Lake was most similar to Lake Nutuvukti (Ca=71% and Mg=23% of cations) which also lies in the Kobuk River drainage and is influenced by the Walker Lake glaciation. In contrast, in the Chandler chain of lakes (Amiloyak through Round, Table 1) located on the north slope of the Brooks Range, Mg equivalents equaled or exceeded Ca, while Na comprised 9-10% of the cations--this formulation is characteristic of waters draining sedimentary rock (Wetzel 1983). Ionic composition in Walker Lake undoubtedly reflects the presence of extensive limestone deposits in the basin (Nelson & Grybeck 1980). In all these lakes (Table 1), however, HCO_3 dominated the anions and sulfate comprised 15-32% of the negative equivalents. This proportion of sulfate is usual in freshwaters (Wetzel 1983) and other surface waters in the Brooks Range

(Livingstone et al. 1958, Slack 1979) but not of the Arctic Slope where waters are low-sulfate (Kalff 1968).

Nutrients--Within Walker Lake, concentrations of TP averaged 2 μg/L (n=79, range 1 to 4 μg/L) and TN averaged 379 μg/L (n=77, range 250 to 510 μg/L). This TN value was virtually identical to the discharge-weighted average in the inflows (Table 2) but lake TP values were typically higher than measured in streams. This difference could partly be a function of our mid-summer sampling program; presumably stream phosphorus concentrations would be greater at the initiation of stream flow following breakup when most annual loading to the lake would occur (Whalen & Cornwell 1985).

Overall, the ratio of TN/TP within the lake was 209 and the discharge-weighted value of this ratio in the streams was 317; these ratios, along with the nutrient values, are indicative of phosphorus limitation. Silica averaged >20 mg/L in the lake and inflows; evidence that not all Alaskan lakes have low silica content (Livingstone et al. 1958).

Algal Biomass--Values of chl *a* averaged 0.60 μg/L within Walker Lake (n=79) and spanned an order of magnitude between 0.13 to 1.32 μg/L. Measurements at the lake surface averaged 0.28 μg/L (n=22), which was lower than chl *a* in nearby lakes (Table 1). There were clear patterns in the distribution of chl *a* pigments within Walker Lake at the time we sampled. First, there was a

general longitudinal gradient in chl a values downlake--chl a in the epilimnion at Site V in the northern basin averaged 0.45 μg/L, while epilimnetic values were between 0.21 and 0.33 μg/L at sites downlake (Figure 1). This pattern also was demonstrated by surface samples (<0.5m) collected from both basins on 11 June 1988; chl a averaged 0.34 μg/L in the north and 0.19 μg/L in the south (n=7 in each basin).

Second, at all sites chl a values showed a subsurface maximum of about 1 μg/L at depths between 21 and 30 m (e.g. Figure 2a). Subsurface chl a maxima were not uniform in thickness or concentration at the five sampling sites. In each case, however, values approximately doubled at some depth within the metalimnion. A maximum of 1-1.3 μg/L was reached in a broad band in the upper hypolimnion and values decreased below 30 m. Despite minor variations in chl a distribution within the water column, the total amount of chl a pigment in the upper 30 m differed by only 25% among sites (18.3 mg/m^2 at IV and 24.8 mg/m^2 at V), and at three of the five sites values were 21.5 ± 0.5 mg/m^2 chl a.

The algal peak was associated with a weak nutricline; based on TN and TP, the strata between 21 and 30 m at the five sampling sites contained some 12% more phosphorus and 6% more nitrogen than the lakewide average for these elements. In many instances, however, the TN and TP content of individual samples from the epilimnion or metalimnion was as great or greater than that measured within the algal peak. This slight trend for total

nutrient content to increase with depth may result from plankton or detritus accumulating in this zone rather than a high nutrient environment caused by dissolved nutrients.

Maximum chl a values were located at depths 1.3 to 2-times the Secchi transparency (14.5 to 17.5 m). Light measurements at Site I show the upper surface of the chl a maxima (21 m) was at about 5% surface light. Based on the distribution of phaeopigments within the various samples we believe the subsurface maximum is composed of healthy algal cells (Kalff et al. 1972, Whalen & Alexander 1986a). Overall, phaeophytin comprised on average 12% of the total pigment in our chl a samples from the lake (n=79, range 0 to 20%) but within each site there was no apparent difference in the proportion of phaeopigments with depth. In fact, one of the lowest values measured (3%) was at the chl a maxima (21 m) at Site IV. With minor exceptions, dissolved oxygen was at or near saturation within the subsurface chl a layer (e.g. Figure 2a).

A subsurface chl a peak of about 1 µg/L was also present below a strong thermocline in Walker Lake during summer 1987 (Figure 2b). Values of chl a in July 1987 at the lake surface and within the hypolimnion were similar to measurements in July 1988; however, the maximum was some 10 m close to the surface in 1987 (Figures 2a and b).

Nutrient Enrichment Experiments--Phosphorus limitation was clearly demonstrated by the results of nutrient enrichment

experiments conducted in situ in Walker Lake (Figure 3). In both basins, chl a was significantly greater than the control only in those treatments including phosphorus. Additions of nitrogen alone did not stimulate chl a growth over the controls, nor did additions of both nutrients together stimulate chl a growth over phosphorus alone (Figure 3). Within the time frame of the experiment, there was no difference in algal response to two levels of phosphorus addition (5 and 10 μg/L). In both trials, phaeophytin was a significantly smaller proportion of total pigment in treatments with phosphorus (Figure 3); evidence that algal chlorophyll was of higher quality than in controls and nitrogen alone (Kalff et al. 1972).

Discussion

Walker Lake is unquestionably oligotrophic as judged by phosphorus and algal chl a, but its nitrogen content was higher than expected in an unproductive waterbody (Wetzel 1983). Studies of surface water elsewhere in the Brooks Range also have shown nitrogen abundant relative to phosphorus (Slack et al. 1979, Whalen & Cornwell 1985). The source of nitrogen in Walker Lake was probably edaphic. This conclusion is based on our measurements in streams (Table 2) and measurements by Ugolini et al. (1987) of 1 mg/L NO_3 in the soil solution of the organic layer in the Walker Lake watershed. Our present hypotheses are that much of the nitrogen in the tributaries originated with nitrogen-fixing lichens that were common within the watershed,

and that alkalinity associated with limestone in the watershed caused high mobility of soil nitrogen (Haynes 1986). In this region, it seems soil phosphorus is relatively immobile and efficiently retained (Whalen & Cornwell 1985).

High nitrogen and low phosphorus concentrations resulted in phosphorus being identified as the element restricting phytoplankton growth. Nutrient limitation experiments clearly demonstrated planktonic algae at the lake surface were responsive to phosphorus additions and the nitrogen supply was adequate for growth. These findings differ from studies on Toolik Lake, Alaska (Miller et al. 1986, Whalen & Alexander 1986b) where both nitrogen and phosphorus are important. Overall, the ratio of chl a/TP averaged 0.3 in Walker Lake, which was identical to the ratio of these factors in a broad range of temperate lakes (Verduin 1988). This ratio varied from 0.1 at the surface to >0.6 within the chl a peak; this increase with depth might result from low-light adaptation of the algae (Pick et al. 1984).

Our data do not permit us to judge whether the chl a maximum in Walker Lake results primarily from settling or in situ growth. Regardless of the major mechanism determining the formation and depth of this deep phytoplankton layer, variation in the onset or pattern of stratification might explain why it was not in the same position within the water column of Walker Lake in 1987 and 1988 (Figure 2). In future studies, it would be worthwhile to determine how this chl a maximum forms, its dynamics, taxonomic

composition, and relative primary production occurring within this subsurface layer.

Acknowledgements

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Figure Legends

Figure 1. Map of Walker Lake, Brooks Range, Alaska, showing the general position of the lake within the state, location of the five sampling sites (I to V), locations of the Nutrient Enrichment Experiments (darkened circles in the north and south basins), and locations of 21 tributaries we sampled. The map was modified from Reanier 1986.

Figure 2. Secchi depth (m) and distribution of chlorophyll a (μg/L x 10), temperature (°C), dissolved oxygen (mg/L) within the water column of Walker Lake at Site II on 10 July 1988 (panel a), and at a mid-lake near Site II on 3 July 1987 (panel b).

Figure 3. Results of Nutrient Enrichment Experiments conducted between 6-11 July 1988 in the south basin, and 7-11 July 1988 in the north basin of Walker Lake (Figure 1). At each site unfiltered surface water was divided among 10 L translucent polyethylene containers (Cubitainers) which were protected from direct sunlight (after Wurtsbaugh et al. 1985). Triplicate treatments received nutrient additions (as K_2HPO_4 or KNO_3) as follows: Low Phosphorus (LP) = 5 μg/L P; High Phosphorus (HP) = 10 μg/L P; Nitrogen (N) = 225 μg/L N; and Nitrogen+Phosphorus (N+P) = 5 μg/L P plus 225 μg/L N. Nutrients were added only on the first day and were considered nominal additions above background. Three cubitainers received no nutrient additions and

served as the controls (C). The containers were incubated at a depth of 5 m which was about one-third or less of the Secchi transparency at these two sites. At the end of the experiments algal growth was measured as chlorophyll a (μg/L). Statistical differences among treatments were analyzed on transformed data (inverse of the square root) by a one-way analysis of variance test followed by a Tukey's HSD procedure (alpha=0.05).

At each site, phosphorus additions, alone or in combination with nitrogen significantly stimulated algal growth relative to the control and nitrogen alone treatment. Chlorophyll a in the LP, HP, and N+P treatments (dark stippling) was significantly different from the controls and N alone treatment (light stippling). These latter two treatments did not differ in chl a.

Figure 4. Proportion of total chlorophyll as phaeopigment in the Nutrient Enrichment Experiment described in Figure 3. Statistical differences among treatments were analyzed on transformed data (angular) by a one-way analysis of variance test followed by a Tukey's HSD procedure (alpha=0.05). At each site, phosphorus additions, alone or in combination with nitrogen showed a significantly lower proportion of phaeophytin relative to the control and nitrogen alone treatments. Phaeophytin (%) in the LP, HP, and N+P treatments (dark stippling) was significantly different from the controls and N alone treatment (light stippling). These latter two treatments did not differ in % phaeophytin.

Fig 1.

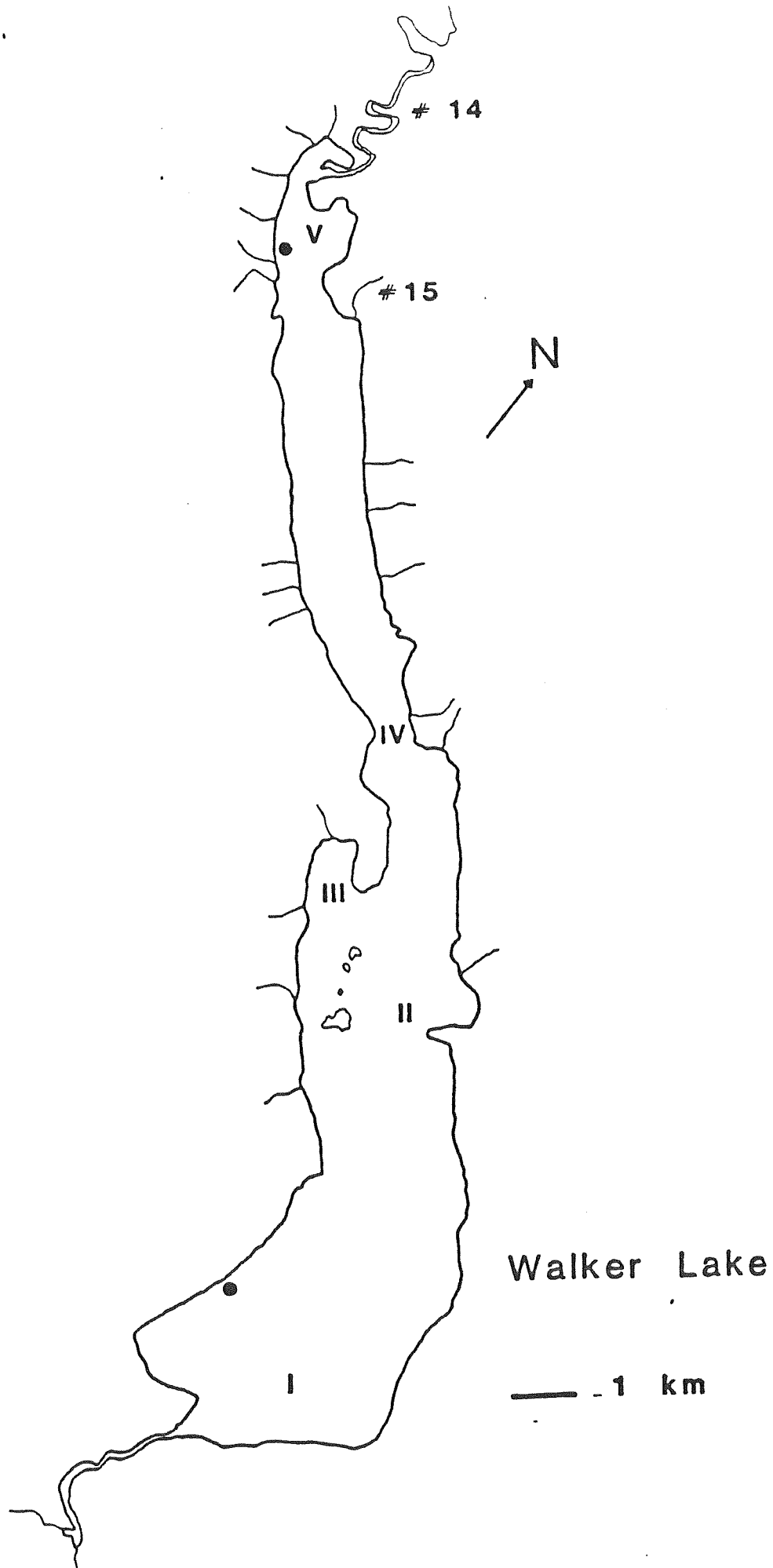


Fig 2.

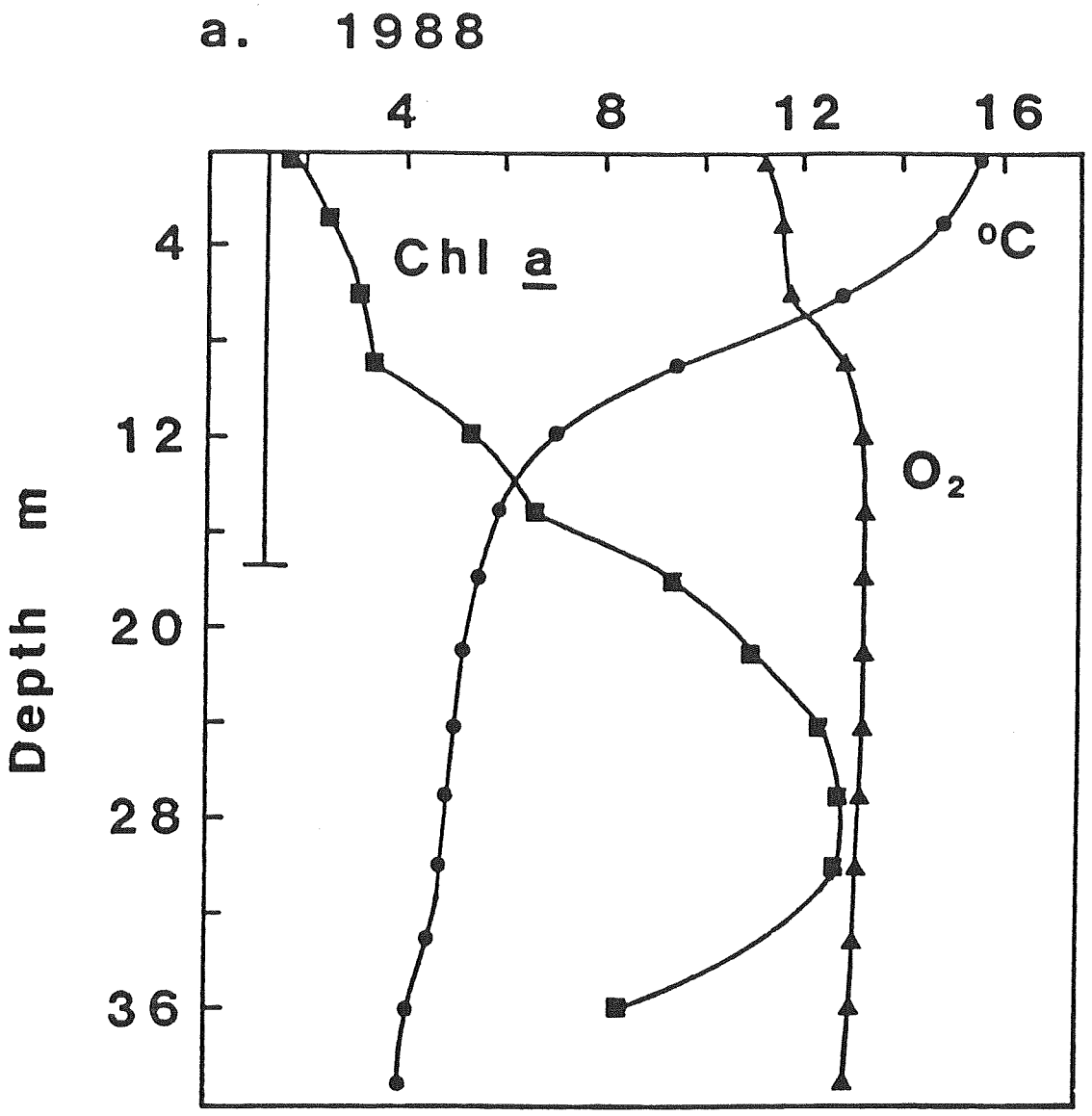
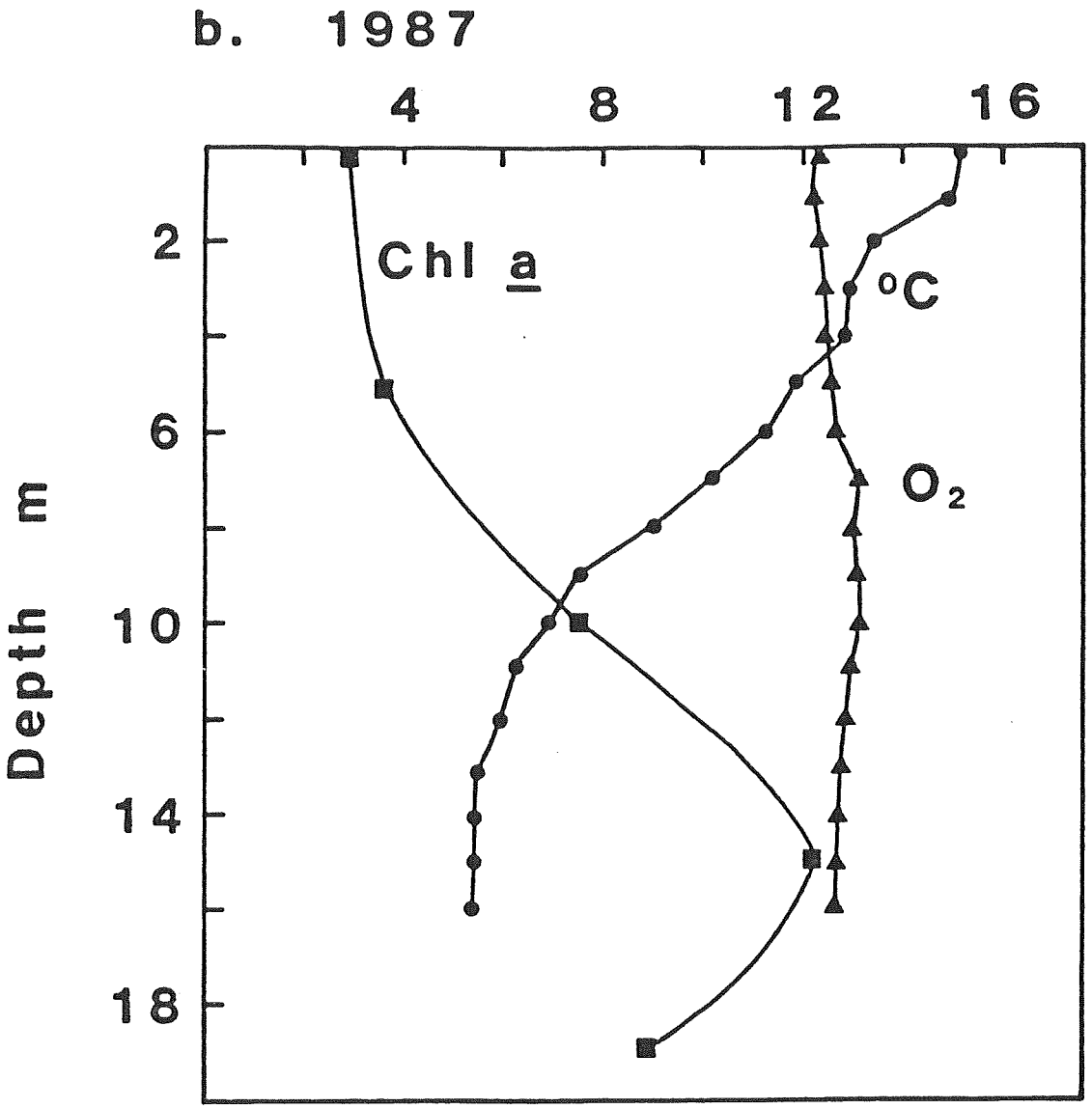
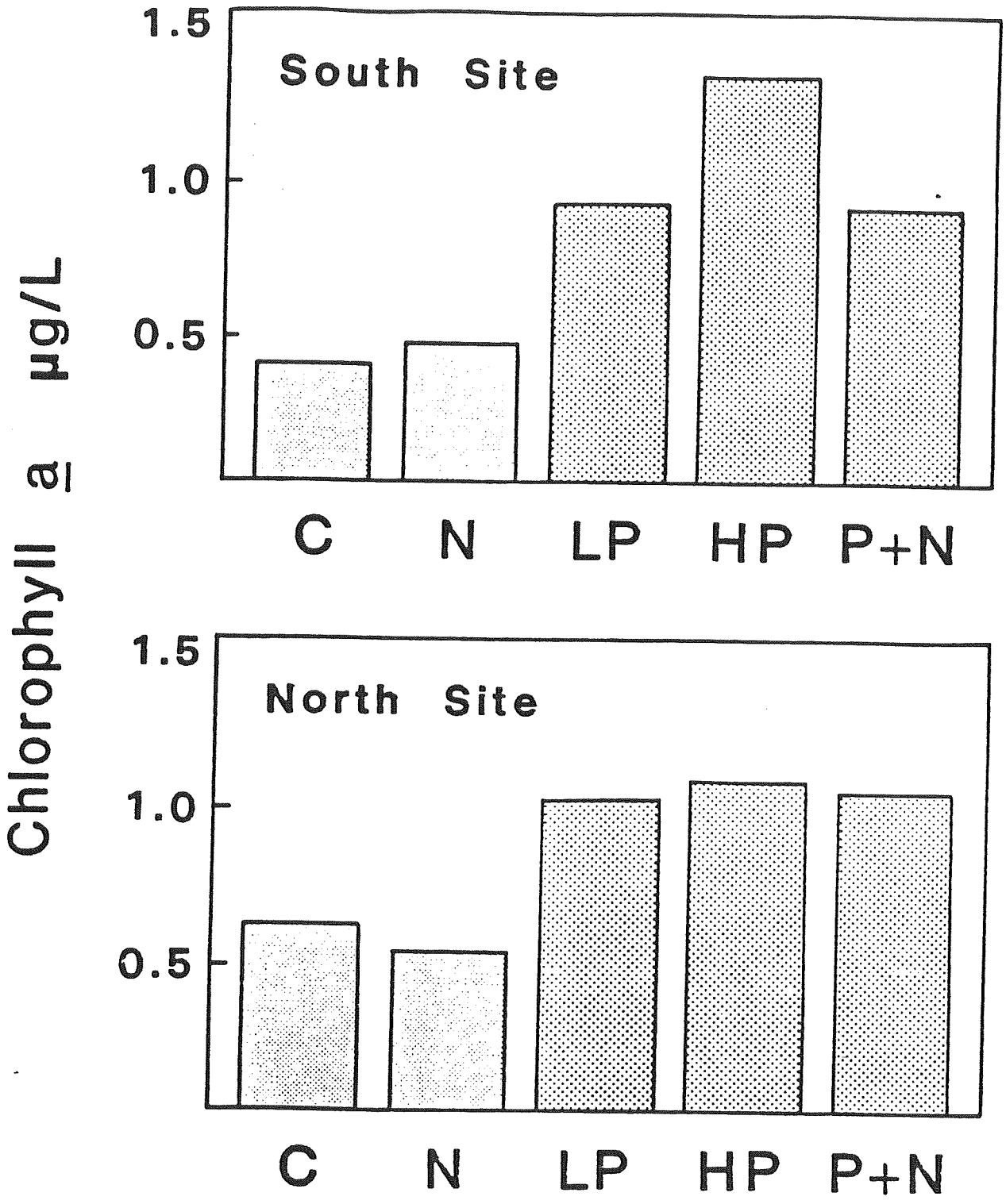


Fig 2




Chlorophyll a µg/L
South Site
1.5
1.0
0.5
C
N
LP
HP
P+N
North Site
1.5
1.0
0.5
C
N
LP
HP
P+N

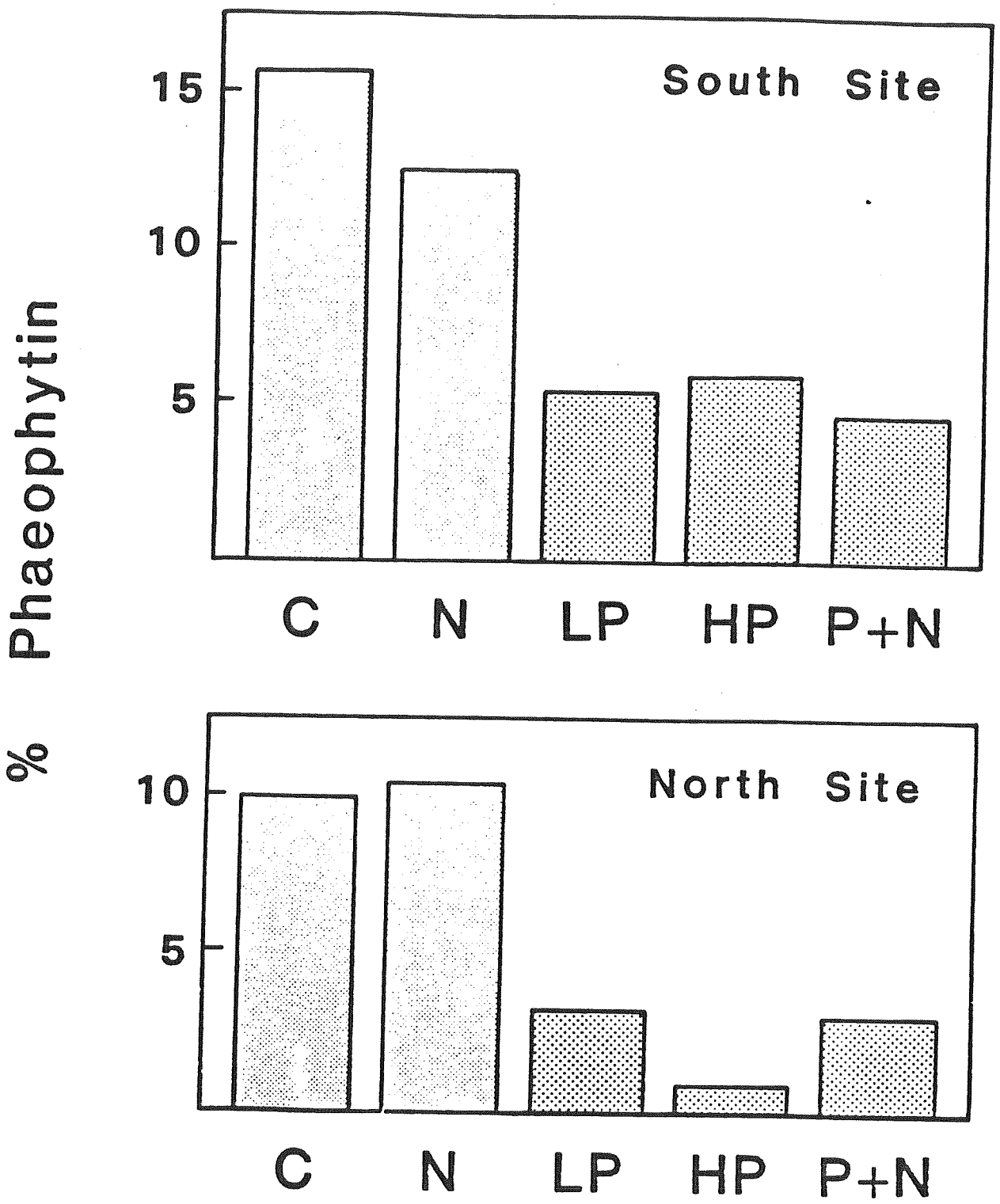

South Site
15
10
5
% Phaeophytin
C
N
LP
HP
P+N
North Site
10
5
C
N
LP
HP
P+N

Table 1. Salinity and chlorophyll values for lakes in the Brooks Range, Alaska during summer 1987 and 1988. Values from the literature are also included. In the text, reference is made to the proportion of HCO_3 among the anions; this value was calculated by difference, we subtracted equivalents for SO_4 and Cl from the total equivalents of cations.

Lake	Year or Reference	Cations meq/L	Ca	Mg	Na	K	HCO_3	SO_4	Cl	Chl*a*[a]
			mg/L							µg/L
Walker	1987	1.42	22.9	2.8	0.45	1.10	---	---	---	0.27
Walker	1988	1.43	22.9	2.9	0.50	1.19	72	9.9	0.5	0.28
Nutuvukti	1988	0.68	9.8	1.9	0.77	0.25	29	6.9	0.4	0.96
Amiloyak	1987	0.21	1.5	1.4	0.47	0.15	---	3.0	0.3	0.95
Chandler	1987	0.50	3.4	3.3	1.15	0.32	---	6.6	0.3	1.21
Little Chandler	1987	0.47	3.5	2.9	1.05	0.33	---	6.3	0.3	1.16
Round	1987	0.48	4.2	2.7	0.95	0.29	---	5.4	0.3	0.70
Peters	Livingstone 1963[b]	0.58	8.2	1.9	0.2	0.1	25	9.4	0.3	---
Schrader	Brown et al. 1962[c]	0.64	7.2	2.7	0.1	2.3	---	---	---	---
Toolik	Cornwell 1983 Whalen 1986	0.60	9.2	1.4	0.51	0.31	24	---	---	1.8

[a] Chlorophyll *a* values from the surface.
[b] Data taken from Table 20.1.
[c] Data taken from Table 2.

Table 2. Limnological characteristics of 21 streams draining into Walker Lake, Alaska measured on 7 and 8 July 1988. Data are presented as the range of values, arithmetic mean and discharge-weighted mean among the 21 streams. Also, data from the two largest streams [numbers 14 (Kaluluktok Creek) and 15, Figure 1] are presented--at the time of sampling, flow in these two streams exceeded flows in the other 19 streams by 4 to 125-fold.

Parameter		Range			Arithmetic[a] Mean	Discharge-weighted[a] Mean	Stream # 14	Stream # 15
		Lowest Value		Highest Value				
Temperature	^{o}C	2	--	9.5	6.5	7.3	9.5	4.5
Dissolved Oxygen	mg/L	8.8	--	12.6	11.4	11.2	11.6	12.1
Calcium	mg/L	14.8	--	47.9	33.8	29.8	19.1	38.3
Magnesium	mg/L	1.2	--	5.4	3.6	3.3	2.7	3.7
Sodium	mg/L	0.28	--	1.16	0.46	0.48	0.59	0.34
Potassium	mg/L	0.09	--	1.63	0.64	1.00	1.63	1.19
Chloride	mg/L	0.2	--	0.4	0.3	0.3	0.3	0.3
Sulfate	mg/L	7.2	--	51.0	19.5	14.7	9.3	13.2
Conductivity	µmhos/cm	90	--	260	187	167	113	210
SiO_2	mg/L	18	--	46	27	23	22	20
Total Phosphorus	µg/L	1	--	2	1.2	1.4	2	1
Total Nitrogen	mg/L	0.22	--	1.24	0.49	0.38	0.26	0.52
Chlorophyll a	µg/L	0.04	--	0.54	0.16	0.14	0.09	0.07
Phaeo Pigments	µg/L	0.0	--	0.18	0.05	0.02	0.02	0.0
Total Fixed Solids	mg/L	0.2	--	1.6	0.7	0.7	0.4	1.2
Total Volatile Solids	mg/L	0.0	--	0.4	0.1	0.1	0.0	0.1

[a]All means are based on samples from 21 streams except for measurements of suspended solids which are based on samples from 20 streams.